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**THE TRANSIENT MAGNETIC STATE**

OF WHICH

VARIOUS SUBSTANCES ARE SUSCEPTIBLE.

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BY

**WILLIAM SNOW HARRIS, Esq.**

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*From the* PHILOSOPHICAL TRANSACTIONS.

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**LONDON:**

PRINTED BY RICHARD TAYLOR, RED LION COURT, FLEET STREET.

1831.



IV. *On the Transient Magnetic State of which various Substances are susceptible.* By WILLIAM SNOW HARRIS, Esq. Communicated by DAVIES GILBERT, Esq. V.P.R.S.

Read June 17, 1830.

1. **T**HE influence of bodies, not permanently magnetic, on the compass needle, has led to some further researches in magnetism of singular importance. The valuable papers of M. ARAGO and other eminent philosophers on this subject, communicated to the Royal Academy of Sciences, together with those of our no less talented countrymen which have appeared in the Royal Society's Transactions, are calculated to excite a deep interest in physics. In presenting to the Royal Society, after such valuable contributions to science, an account of some inquiries which I have myself been led to make in this branch of natural knowledge, I am encouraged by the belief, that whilst the deductions are for the most part derived from simple and direct experiments, the investigation has been carried on under new conditions; and that although some facts already made known, have been again referred to, it will nevertheless be found to contain results of sufficient consequence to render it not unworthy of notice.

I have been particularly led to persevere in this investigation, at various times, from having observed (Edinburgh Journal of Science, vol. v. p. 325.) that the reciprocal action of a rotating metallic disc, and a magnetic bar, is not considered by M. ARAGO as the result of any magnetism induced in the disc, but is attributed by him to some new force as yet undiscovered:—and also, from the circumstance, that the magnetic susceptibility of non-metallic bodies, seems not to have been in many instances satisfactorily established:—two inquiries of considerable importance.

2. When these researches were first commenced\*, a curious effect was observed, evidently resulting from vibration, which it may be of consequence to mention.

A thin circular ring of copper of about half an inch wide, ten inches in

\* In 1826.

diameter, and about  $\frac{1}{40}$ th of an inch thick, being delicately balanced on a fine point, by means of a transverse bar of wood carrying an agate centre, was placed on a firm screen of paper strained tight on a wood frame, and covered by a glass shade; two powerful magnetic bars were caused to revolve in a horizontal plane, beneath the screen, with their poles immediately under the ring. The ring, as in all the previous experiments of the same kind, soon acquired motion in the direction of the revolving bars, which could be arrested and reversed at pleasure, by changing the direction of the rotation. It was however soon discovered, that a similar effect could be produced when the magnets were not present, merely by the action of the rotating apparatus. This last consisted of a train of wheels resting on a firm pavement of thick stone; the frame carrying the screen being supported over it on blocks of oak.

As it was of consequence to ascertain how far small vibratory impulses communicated to the screen, could cause the phenomena just observed, a continuous but gentle vibration was induced from one corner of it, by a slight tapping, which, after a few minutes, communicated motion to the ring in a constant direction; on transferring the vibrations to the opposite side of the frame, the ring was again brought to rest, and caused to revolve in an opposite direction. A similar result was obtained when a compass needle, and light needles of other substances were substituted for the ring of copper.

3. These results led me to place the copper circle in an exhausted receiver, on a strong plate of glass, and to suspend the whole on a convenient frame by means of lines passing from firm walls; the revolving bars being placed as before, immediately under it. In this instance, however, I failed at the same distance to move the ring, nor could a fine compass needle similarly placed be made to deviate more than a few degrees from its meridian, when exposed to the influence of a rapidly revolving disc. This result is quite sufficient to show how minute a cause may render delicate investigations with a rotating body unsatisfactory; more especially when connected with a heavy apparatus: even in the case of screens it does not seem quite clear that certain impulses may not be propagated through them, of sufficient magnitude to act on a very finely suspended needle or disc; when the screens are thin and porous, the chance of this is greatly increased, and in cases where a screen only is employed without a shade; similar results would doubtless ensue from vortices





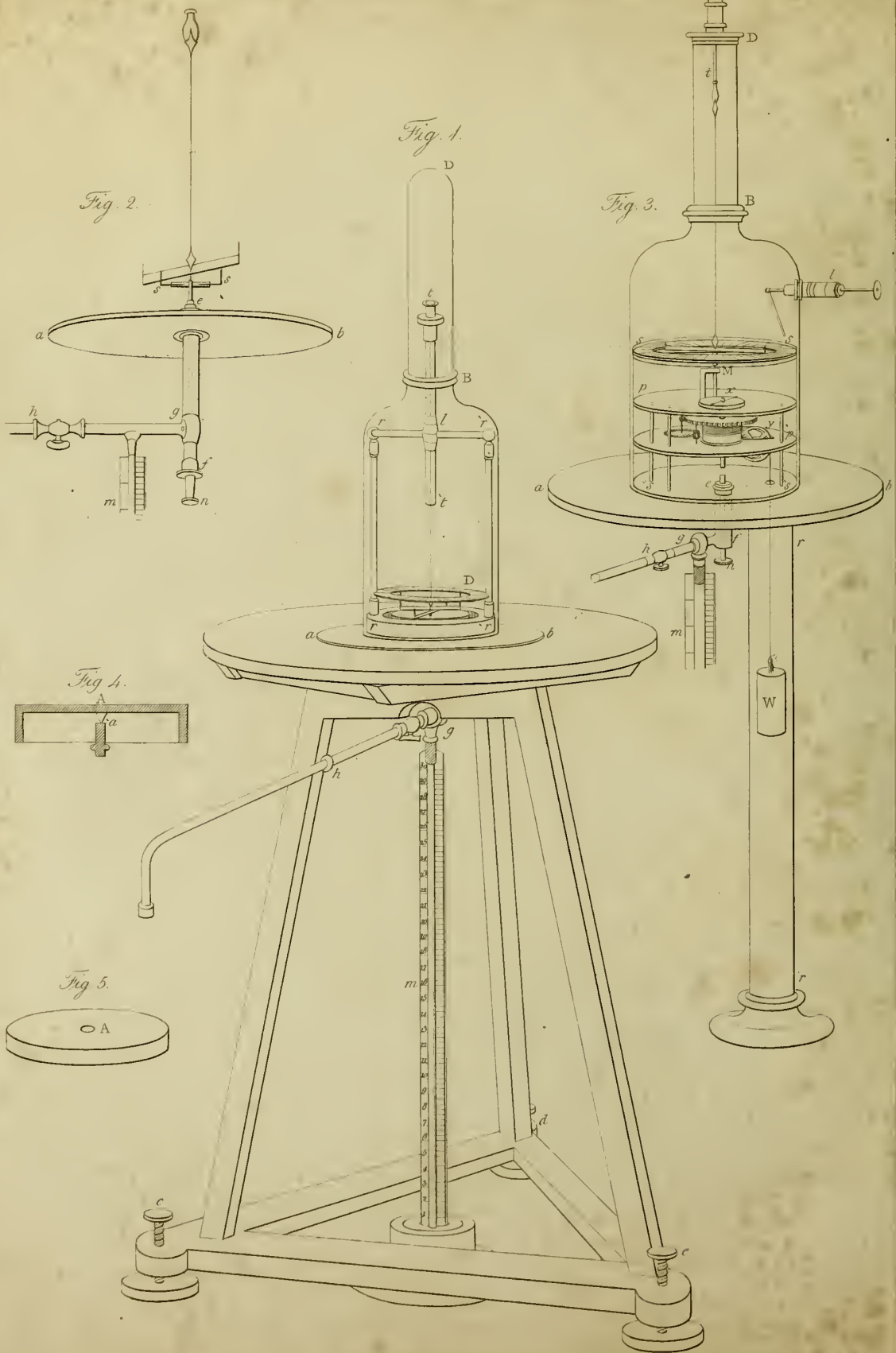




Fig. 8.

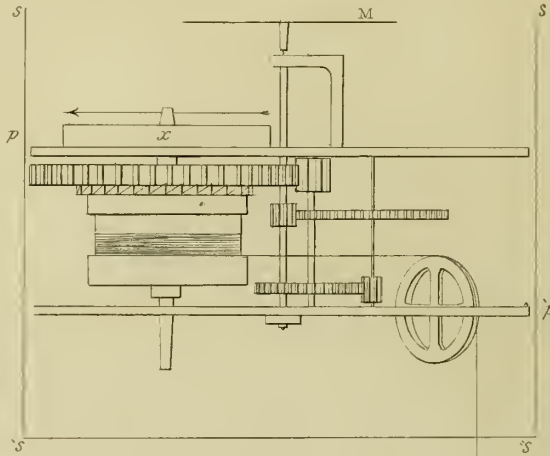


Fig. 6.

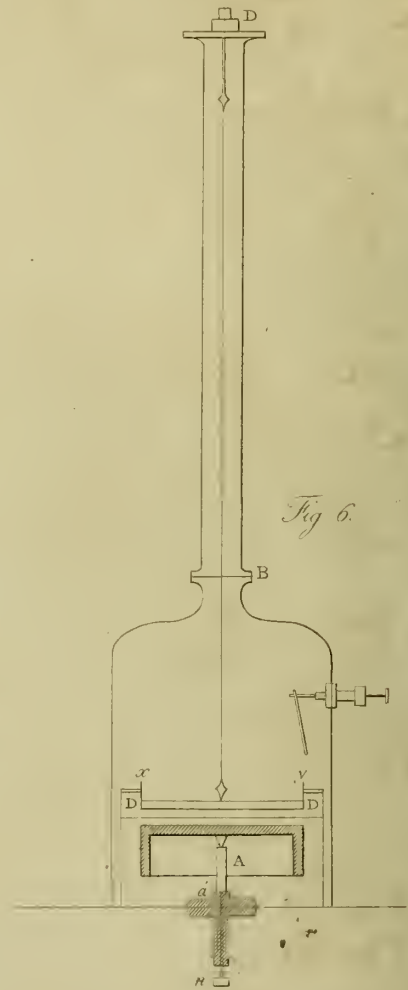


Fig. 9.

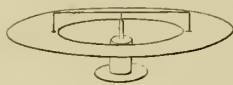


Fig. 7.

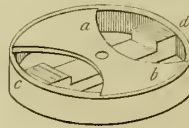


Fig. 10.

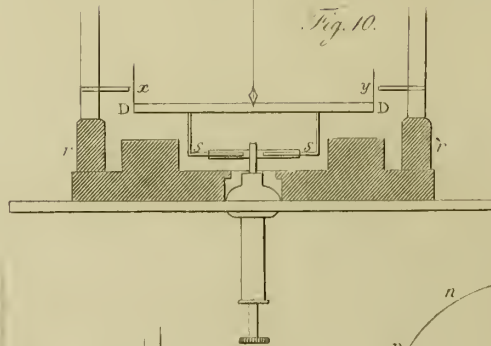


Fig. 11.

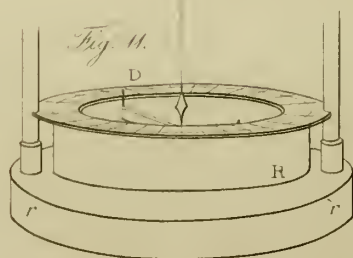
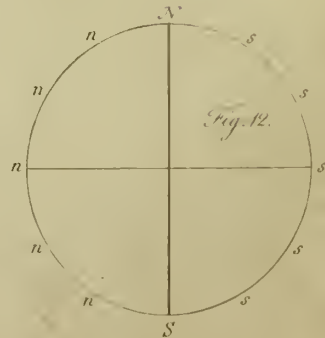


Fig. 12.





in the whole mass of the surrounding air. I do not however mean to infer that such sources of fallacy have not been fully calculated on, or guarded against in the many valuable papers already alluded to: I rather mention them as a reason for adopting a method of experimenting, differing from the preceding, and which might insure an unmixed result. To this end the experiments were continued in an exhausted receiver, effectually screened from vortices, and liberated from the influence of a resisting medium; and in case of employing a rotating body, with a rotation continued so smoothly and evenly, as not to cause any vibration capable of inducing motion.

4. The following is a description of the different mechanical arrangements resorted to. A circular plate of close fine-grained slate, *a b*, fig. 1, 2, 3, of about half an inch thick and a foot in diameter, being carefully ground true, in order to fit it for the purposes of an air-pump plate, was nicely finished by rubbing it over with a mixture of oil and wax.\* This plate is supported on a firm stand and frame, as represented in fig. 1, furnished with levelling screws *c, d, e*. A short brass cylinder *e, f*, fig. 2 & 3, is fixed under the plate by means of a hole in the centre, and two brass collars ground true to its surface, and between which the plate is compressed: so that with a little grease, and a strong nut at *e*, fig. 2, 3, the joint is rendered air-tight. The cylinder *e f* connects laterally with a short pipe and stopcock *g h* leading to a good air-pump; a long barometer gauge *m*, fig. 1, 2 & 3, being attached to the pipe to indicate the state of the exhaustion. A straight rod of brass *n e*, having a milled head at *n*, passes through a compressed collar of fine cork at *f*, and is sufficiently free above in the cylinder to allow of the action of the pump; this rod is occasionally employed when furnished with a transverse bar at *e*, having two stops *s, s*, fig. 2 & 10, to liberate a magnetic bar in an exhausted medium, when retained at any angle of deviation from its meridian, or to effect any other required operation, as in fig. 3.

5. The revolving body A, fig. 4 & 5, consists of a circular disc of about five inches diameter, and 0.125 of an inch thick; united to a deep ring of the same

\* The application of this substance to the purposes of an air pump-plate will be found extremely convenient, more especially when it is desirable to avoid the presence of a large mass of metal. It is a very economical and efficient substitute for glass or brass, and retains its form without liability to warp; and is an application as far as I can learn quite new.

substance, or otherwise to a ring of lead. This disc has smooth rounded edges, and is balanced on a fine central point A of hardened steel, in such way that the centre of gravity and centre of motion coincide as nearly as possible; the whole is sustained on a small agate cup, set in a short cylindrical piece of brass  $\hat{a}$ , fig. 4, and screwed, when required, into the shoulder of the brass cylinder which passes through the round hole of the pump-plate as represented in fig. 6. The sliding rod  $n e$  above mentioned is in this case withdrawn for a short distance within the cylinder. The disc is set in motion at the rate required by means of a line wound rapidly off it, from a train of wheels; it is then covered with a screen, and with a receiver, as in fig. 6, and the exhaustion made as perfect as possible; in which case it will continue to revolve for a considerable time.

A simple or compound magnet is put into rapid rotation in a similar way, being previously mounted on a ring of lead; besides straight bars, a compound magnet was employed for this purpose, having its extremities turned up in a perpendicular direction for about an inch, as in  $c d$ , fig. 7, and occasionally a circular disc of magnetised steel, fig. 5. The former has its point of support fixed in a transverse bar of brass  $a b$ , fig. 7, which projects in a circular hole drilled through the centre of the bars.\*

6. When it became necessary to measure with great precision the rapidity of rotation, the machine represented in fig. 3 & 8 was employed. It consists of a metallic disc M kept in motion by a delicate train of wheels and pinions  $p p'$ . The rapidity of the rotation being accurately measured by an index  $x$ , moving on a small circle divided into twenty parts. The weight W, fig. 3, which by its descent keeps up the rotation, falls in a tall narrow receiver  $r r'$ , supported against the under surface of the pump-plate.

A circular hole is drilled at  $s'$  through the plate for the silk cord to pass, from the pulley at  $y$ ; by means of this hole also, the receiver  $r r'$  is exposed to the action of the pump. The machine is wound up and set in motion by means of the brass rod  $n e$ , fig. 3, already described (4), without disturbing the state of the exhaustion; the extremity of the rod being formed into a key.

The revolving disc is screened by glass or any other substance, over which

\* This method of obtaining a rapid rotation in an exhausted receiver, suggested itself on perusing the account of Mr. SERSON'S horizontal speculum in the Royal Society's Transactions.

is placed a graduated circle of fine milled board, sustained in a light circular ring of wood. The screen and ring are moveable with friction in a hollow cylinder of glass  $ss's'$ , fig. 3, so as to be adjusted at any required altitude.

7. The receivers employed to inclose these various bodies are for the most part such as are represented in fig. 1, 3 & 6; they have an open neck at B ground to a flat surface which admits of the altitude being increased by the addition of a second narrow receiver BD: this last is also ground flat at the point of union; thus, by the aid of a little grease, an air-tight joint is easily obtained in the usual way. The upper receiver BD is either closed above, or open, with a ground flat rim in order to apply a brass plate D carrying a brass rod  $t$  in an air-tight collar. The rod  $t$  is for the convenience of raising or depressing light discs or needles suspended in the receiver below: these receivers vary from eight to forty inches in altitude, and from one to three inches in diameter; so that the filament of silk for suspension may, when required, be upwards of four feet in length.

8. The substances exposed to the influence of the revolving bodies are formed into light needles or bars, or otherwise into flat circular rings, fig. 9, and are either suspended or nicely balanced on points. For the purpose of retaining them at rest until the exhaustion is complete, and when the stop  $e$ , fig. 2, already explained (4) cannot be used, there is an angular lever  $l$ , fig. 3, which passes in an air-tight collar through the side of the receiver, carrying at its extremity a common reed  $s$ , which being tubular is easily fixed on it; hence it can be extended at pleasure.

9. The following are the results of some experiments with the apparatus above described.

(*a*) A circular disc of copper being put into rotation at the rate of 500 revolutions in a minute, was left unscreened under a receiver, and a fine reed suspended over it by a filament of silk; the reed was retained at rest, until the exhaustion was completed to within 0.4 of an inch of a good barometer, when it was set free. The reed rotated freely at any distance at which it could be placed from the revolving disc, and which at the greatest amounted to eight inches. The motion of the reed diminished with the rapidity of the rotation of the disc and with the torsion of the silk; but its motion could be again restored by admitting a small quantity of air into the receiver.



(b) In a tall receiver of about two feet high a reed similarly placed rotated at a distance of eighteen inches from the revolving disc, when the exhaustion was within six inches; but it remained at rest at a foot distance, when the exhaustion was carried to within 0.4 of an inch.

(c) The rotating disc being screened by a thin plate of glass or varnished paper fitted close upon a short hollow cylinder of glass or wood, the reed remained at rest, although placed within one fifth of an inch of the screen.

(d) A cylindrical magnetic bar revolved rapidly in an exhausted medium, when within one fifth of an inch distance from the disc; but only deviated from the meridian 40 or 50 degrees when the screen above mentioned was interposed. The disc in this experiment revolved at the rate of 400 revolutions in the minute.

(e) Needles of glass, wood, and metallic substances not permanently magnetic, remained at rest when the rotation exceeded 600 revolutions in a minute, whether suspended by filaments of silk, or otherwise placed on points and supported on the glass screen. When the rotation exceeded 1000 revolutions in a minute, and the exhaustion was inconsiderable, they were sometimes slightly moved.

(f) Rotating magnetic discs and bars induced motion in metallic discs freely suspended at one fifth of an inch distance, when their thickness was about four times as great as ordinary tinfoil, and when the rotation exceeded 500 revolutions in a minute; the rotating body being screened by any intervening substance except iron, which last, as already observed by Mr. HERSCHEL and Mr. BABBAGE, completely intercepted the effect\*. But light discs of wood and paper, and discs of paper covered with silver or gold leaf, remained at rest when within  $\frac{5}{20}$ ths of an inch distance from the rotating body.

(g) A disc of iron or tempered steel did not communicate motion to any

\* Philosophical Transactions of the Royal Society for 1825.

Although a sheet or two of tinned iron completely intercepts the influence of a revolving magnet on metallic discs generally, it does not appear to do so when the disc acted on is also of iron. I found, however, that a screen of sheet iron of about one fourth of an inch thick materially diminished the influence even on an iron disc, so that the rotation of an iron disc by the influence of a revolving magnet is reduced nearly to that of a copper disc of the same dimensions when the iron screen is not present. This curious effect of screens may possibly lead to some further elucidation of the nature of magnetic influence.



substance not permanently magnetic ; nor could motion be induced by the action of such substances on each other, however near they could be placed with an intervening screen ; although the rapidity of the rotating body was caused to exceed 1000 revolutions in a minute.

(*h*) A needle of soft iron was not influenced by a copper disc revolving at the rate of 600 times in a minute ; but rotated freely when surrounded by a helix transmitting an electro-magnetic current.

(*i*) A disc of tempered steel not magnetic, after simple contact with a powerful magnet acquired sufficient force to induce motion in metallic rings.

(*k*) A needle of tempered steel was not influenced by a rotating disc of soft iron at the distance of one fifth of an inch, and revolving at the rate of 600 times in a minute ; but the needle revolved rapidly after simple contact with a magnet.

(*l*) Magnetic needles delicately mounted on an horizontal axis so as to admit of motion in a vertical plane, remained at rest when the axis was perpendicular to the radius of the revolving disc ; but the needles appeared to be carried in the direction of its motion when the axis was turned in the same plane.

10. The above facts seem to show very clearly, that the presence of permanent magnetism, and a susceptibility of magnetic induction are essential conditions in the phenomena of rotation hitherto observed : at least this deduction is fair for all distances between the bodies at which they can be well placed with an intervening screen : without a screen it seems extremely difficult ever to arrive at a satisfactory result ; since even in a very rare medium (Exp<sup>ts</sup> (*a*), (*b*), (*c*), (*d*)) vortices are produced by the action of a rapidly revolving body, although with perfectly rounded and smooth edges, capable of carrying round light substances ; and although separated from such substances by a considerable interval. So far therefore as this method of examining the influence which bodies not permanently magnetic can exert on each other extends, it seems not susceptible of the requisite precision ; and is, therefore, in a great degree inadequate to detect any very minute and delicate force, which can be supposed to arise from such an influence.

11. The law according to which metallic or other discs in a state of rotation influence a permanent magnet seems to be directly as the rapidity of the rotation, and inversely as the squares of the distances between the attracting

bodies: at least for such distances as can be conveniently resorted to with an intervening screen. In order to investigate this, I resorted to the machine already described (6) and represented in fig. 3 & 8. By a few previous trials such weights were found as might in a short time impart to the rotating disc the respective velocities of 178.5, 357 and 714 revolutions in a minute; which numbers are to each other as the numbers 1, 2, 4: and by means of the index and graduated circle  $x$ , fig. 3 & 8, the deflections of a magnet could be taken when these velocities were attained. This point was determined by means of a valuable chronometer of a peculiar description which my friend Lieut.-Col. H. SMITH, F.R.S. was so good as to lend me for the purpose; it can be set going, and stopped again at pleasure, and is capable of registering an observation to the  $\frac{1}{60}$ th part of a second. As the graduated circle is divided into twenty parts, it is presumed that the rate of motion can in this way be ascertained with sufficient accuracy; and thus any little acceleration caused by the descending weight is not of consequence.

12. A magnetic bar being suspended as in fig. 3, was in the first place accurately adjusted at the point of contact to the plane of the body intended to be put in motion, and which consisted of a flat ring of copper of an inch wide, and about 0.05 of an inch thick. The bar was then raised from the ring through a distance equal to five turns of a micrometer-screw at D, each turn of the screw being equal to the  $\frac{1}{20}$ th of an inch: the screen  $s$  was then interposed, and the whole covered by a receiver, and exhausted.

(*n*) The machine being set in motion, the deviation of the bar amounted to  $24^\circ$  when the velocity was 357 revolutions in a minute: on increasing the velocity to 714 revolutions in a minute, or double the former, it amounted to  $56^\circ$ . The exhaustion in these experiments was carried to within 0.5 of an inch. Taking the sines of the angles of deviation as a measure of the force urging the bar, we have the respective numbers .829038 and .406737, which are very nearly in the same ratio as the respective velocities; that is to say as 2:1.

(*o*) The bar being adjusted to within a distance of the ring equal to four turns of the screw, the deviation of the needle amounted to  $38^\circ$  when the velocity was 357 revolutions in a minute: on raising the bar by four additional turns of the screw, the deviation decreased to  $9^\circ$ . Taking the sines of these angles as before, we have for the corresponding distances, the numbers .615661

and .156434, which may be considered as very nearly in the inverse ratio of the squares of the respective distances.

In the following Table are given the deviations of the bar, corresponding to other distances and velocities.

TABLE I.

(A)			(B)			(C)		
Velocity of rotation, 178.5			Velocity of rotation, 357.			Velocity of rotation, 714.		
Distance in turns of Mic <sup>r</sup> -Screw.	Angle of Deviation.	Sine of Deviation.	Distance in turns of Mic <sup>r</sup> -Screw.	Angle of Deviation.	Sine of Deviation.	Distance in turns of Mic <sup>r</sup> -Screw.	Angle of Deviation.	Sine of Deviation.
4	18 <sup>o</sup>	.309017	4	38 <sup>o</sup>	.615661			
5	12	.207912	5	24	.406737	5	56	.829038
			6	16	.275637			
8	4.5	.078459	8	9	.156434			
10	3	.052336	10	6	.104528	10	12	.207912

It appears by the above Table, that the influence of the ring is directly as the rapidity of the motion, and inversely as the squares of the distances: we observe a little discrepancy in some of the numbers, but the general agreement is very close and remarkable. A complete agreement cannot be expected; for supposing even the most perfect manipulation, there will always arise in experiments of this kind many causes which disturb a numerical identity\*.

13. Being desirous to extend these inquiries concerning the transient magnetic state, of which various substances appear to be susceptible, I subsequently laid aside the rotating discs, as a means of detecting these minute forces for the no less refined, and perhaps still less exceptionable method of a vibrating bar; since what is termed the magnetism of rotation, seems in fact to be

\* In estimating the distance between the surfaces of the attracting bodies, the revolving disc was purposely made as thin as possible, so as to admit of its being considered without any sensible thickness. With respect to the magnet, the foregoing experiments with screens clearly show, that an intervening ferruginous mass completely intercepts the attractive force upon non-ferruginous substances. If any portion of the bar beneath the surface contiguous to the revolving body be supposed to operate upon the ring, such portion must necessarily act through the intervening iron; which it cannot do (Exp. *f*)(11). This view seems to derive much confirmation from experiment, since on vibrating an extremely thin needle of sheet steel over a metallic disc, the comparative results do not vary from those obtained by means of a bar of half an inch thick.



nothing more than the presence of a temporary magnetic development induced in successive points of a body by the action of a permanent magnet, the body being supposed in motion. If the body therefore be at rest, this development will restrain the motion of a bar vibrating near it, and so diminish the amplitude of its oscillations; and thus by determining the number of vibrations performed in a given arc, we may from thence arrive at a comparative value of the force in action.

To this effect the bar already mentioned (12) was suspended, and exposed to the influence of different substances, in the following manner.

Two perpendicular rods of glass  $rr$ ,  $r'r'$ , fig. 1, furnished with foot- and cap-pieces are fixed in a solid block of mahogany  $rr'$ , fig. 1; these rods by the intervention of a short wood cylinder  $l$ , and two horizontal rods, also of glass,  $rl$ ,  $r'l$ , sustain a glass tube  $tt'$  which slides with friction through the cylinder. This tube is furnished with a cap-piece at  $t$ , through which passes a brass rod: the magnetic bar is suspended from this rod by a filament of silk, and is finally raised or depressed to the required altitude by a micrometer-screw at  $t$ : the altitude of the glass tube  $l$  being previously fixed. The centre of the mahogany block is hollowed into a cylindrical cavity as represented in fig. 10, and is firmly fixed upon the pump-plate by means of the screw and shoulder projecting through the brass collars (4). Its outer part is also depressed, leaving a cylindrical projection of about one fourth of an inch deep, 4.7 inches diameter, and 1.25 inch wide.

The graduated circle of stout card-board D already mentioned (6) slides with friction between the glass rods, so as to be easily adjusted at any given point. The bar is retained at the given angle from its meridian, and again set free, when the exhaustion is sufficiently complete, by means of the lever and double stop before explained (4), and which moves in the interior circular cavity of the block, fig. 10.

This method of arresting the bar seems to be of some consequence to the experiment; for if one pole only be checked, the force operating on the other, will for an obvious reason, give the bar a swinging motion, which is very undesirable, but which is here effectually prevented; so that when set free it will appear to oscillate as if mounted on a fixed centre. The checks by which the bar is thus arrested, are so contrived as to be independent of each other,



and are moveable with friction in a small tube of brass as at *ss*, figs. 2 and 10, and may consequently be adjusted with great nicety. The tube in which the checks are fixed is sustained in a horizontal direction in the extremity of the rod, which passes into the receiver through the centre of the pump-plate.

14. The substances to be submitted to experiment, are formed into rings as at *R*, fig. 11; in these the bar is caused to oscillate. Each ring is about one inch in height, of any convenient thickness, and 4.75 inches interior diameter, so as to admit of its being accurately adjusted on the cylindrical shoulder of the circular base, fig. 10.

15. In applying the method of an oscillating bar to the investigation of minute and transient magnetic forces, it seems essential to keep in view the following interesting fact; viz. the influence of bodies, not susceptible of permanent polarity, on the state of oscillation is such, that the amplitude of the vibrations only is diminished, not their duration: that is to say, whether a bar vibrate in free space, or otherwise near plates, or in rings of these substances, still the number of oscillations in a given time, considered as a unit of time, does not vary, although the bar is sooner brought to rest when under the influence of such bodies, than when freed from them, whatever substance be employed, and at whatever distance the influence be exerted.

This fact seems materially to distinguish the peculiar influence of non-magnetic substances, from a case of permanent polarity; by which last, an oscillating bar is not only brought to rest in less time, but the rate of vibration is very sensibly increased. We cannot therefore, as in the latter instance, resort to the common law of pendulums, and take the square of the number of oscillations performed in a given time as a measure of the force in action, since the time of each oscillation does not sensibly vary; we must therefore adopt some other method.

16. In order to arrive at a comparative value of the influence of any substance on a vibrating bar, I have been led to employ the following formula,  $\left(\frac{a}{b} - 1\right)r$ ; which seems to apply in a very remarkable manner to the results of experiment; in which *a* represents the number of oscillations in a given arc in free space, *b* the number in the same arc, when exposed to the influence of a substance not permanently magnetic, and *r* the retarding force

by which the bar tends to rest in free space ; the oscillations being supposed to take place in an exhausted receiver. Thus, if in free space 420 oscillations are performed before the arc of vibration is reduced from  $45^\circ$  to  $10^\circ$ , and the number of vibrations in the same arc, are 30 and 20 respectively, when the bar vibrates under the influence of two given substances taken in succession, and whose magnetic energies we propose to compare with each other ; then the energy of the one may be expressed by  $\left(\frac{420}{30} - 1\right) r$ , and that of the other by  $\left(\frac{420}{20} - 1\right) r$ ; that is to say, their energies will be to each other as 13 : 20\*.

17. Previously to examining the susceptibility of substances generally to magnetic influence, the number of vibrations was first determined between  $45^\circ$  and  $10^\circ$  in air, under a glass-shade ; then the number in the same arc also in air, when the bar was surrounded by a ring of wood of one fifth of an inch thick, and an inch deep ; each pole being  $\frac{3}{40}$ ths of an inch distant from the interior of the ring : this being carefully ascertained, the same was repeated in an exhausted receiver ; the results are as follow :

TABLE II.

Number of Vibrations from $45^\circ$ to $10^\circ$ .			
In air.		In exhausted receiver.	
Vibrations in space.	Vibrations in ring of wood.	Vibrations in space.	Vibrations in ring of wood.
232	210	420	308

It may be seen in this experiment that the ring of wood exerted a very sensible retarding power on the vibrations of the bar, which is more apparent when the impediment to motion arising from a resisting medium is removed. I submitted to experiment in this way, in a pneumatic vacuum, a few rings of

\* A magnetic bar whilst vibrating under the influence of any substance, must be considered to be operated on by two retarding forces ; one by which it would be eventually brought to rest, supposing the given substance away ; and another resulting from induction. The number of vibrations in a given arc, or their differences, therefore do not seem to be a measure of the latter force, since some portion of the former will always enter into the result of the experiment.

different substances similar to the above, and found their influence on the vibrations very decided, although the differences in their respective magnetic energies was not very apparent. The substances tried, with the respective number of vibrations, and their comparative energies as deduced from the formula, are given in the ensuing Table.

TABLE III.

Substances.	Vibrations from 45° to 10°.	Comparative energies as deduced from formula.
Distilled water, temp. } 20° FAHR..... }	330	0.27
Honduras mahogany . . .	308	0.36
Statuary marble . . . . .	306	0.37
Freestone . . . . .	308	0.36
Annealed glass, $\frac{1}{8}$ -inch } thick . . . . . }	310	0.35

18. By employing the above substances in larger masses, the effect on the bar seemed to be greatly increased: although the difference in the comparative energies of wood and marble, the only two substances which I had an opportunity of trying, is still not very great. In the following Table are given the results of some experiments with a ring of statuary marble of 1.75 inch thick, and with a similar ring of Honduras mahogany, as compared with the influence of two rings of the same substances of only one fifth of an inch in thickness.

TABLE IV.

Substances.	Wood.		Marble.	
	0.2	1.75	0.2	1.75
Thickness of ring in inches . . .				
Vibrations from 45° to 10° . . .	308	280	306	265
Ratio of magnetic influence as } deduced from formula . . . }	0.36	0.50	0.35	0.59

19. The influence of the substances being observed to depend in great



measure on the mass, it seemed of consequence to ascertain how far the energy might vary with the density. Several kinds of wood therefore of the above dimensions were subjected to experiment, whose specific gravities greatly varied; but there did not appear, after many trials, any perceptible difference on 280 vibrations. The woods tried were, *Lignum Vitæ*, Yellow Pine, African Oak, Honduras Mahogany, and Teak. All these reduced the vibrations of the bar from 420, the number performed in free space, to 280, the number performed when surrounded by the wood; the vibrations being taken from  $45^\circ$  to  $10^\circ$ , in an exhausted receiver.

20. I endeavoured to detect the magnetic energy of fluid bodies by vibrating the bar in an exhausted receiver, with its poles within the  $\frac{1}{6}$ th of an inch of the glass; the receiver being surrounded at that part opposite the pole of the magnet by the particular fluid, the subject of experiment. In this case the fluid was retained in its situation by means of an external check of glass ground to a glass-plate, on which the whole was sustained; the plate being supported on a ring of glass placed over and in connection with the pump-plate below; and the surfaces of contact ground, so as to fit air-tight. I failed however in arriving at any decided result; the amount of the retardation with sulphuric acid, for example, not appearing greater than was fairly attributable to the influence of the glass alone: even a saturated solution of sulphate of iron did not seem to exert in this way any sensible influence. By means of a very great number of vibrations, and a powerful bar, however, the energy of fluids, if such exist, might possibly become appreciable.

21. The inductive influence on metallic bodies being the most decisive, they are perhaps better adapted to the purposes of experiments relating to the influence of mass and density, or to the law according to which the inductive effect increases, as the distance from the magnet decreases, than any other kind of substance. Before examining, therefore, the comparative energies of various metals, I endeavoured to arrive at some further conclusions in this interesting part of the inquiry. In order to examine the comparative energies when the quantity of matter was varied, twelve concentric rings of copper were employed similar to the former ring of wood (17), except in thickness, which amounted to .025 of an inch: these rings were turned up with sufficient accuracy, and fitted very fair and close one within the other. The num-



ber of vibrations was first determined in the interior ring alone, after which a second was added, and the number of vibrations again determined, and so on to eight rings; when the increased effect became almost inappreciable.

TABLE V.

Number of rings . . . . }	1	2	3	4	5	6	7	8
Vibrations . . . .	44	30	24	21	19+	17	16+	16
Ratio of force .	8.54	13	16.5	19	21+	23	24+	25

The increments in the effect on the bar appear by the above Table continually to decrease, so that after a certain number of laminæ they seem to be no longer appreciable; hence the numbers expressing the comparative energies would become at last equal, and such was found to be the case, the number of vibrations with twelve rings being no greater than with ten\*.

22. The quantity of matter in the foregoing experiment being actually divided into concentric rings, I endeavoured to ascertain how far the above results depended on the sum of the whole, or of any number of them; with this view the number of vibrations was determined for each ring, when opposed to the bar in the same relative situation which it occupied in the mass, so as to obtain the separate effect due to any particular ring. These separated results were as follow.

\* It is not improbable that some principle of this kind is the immediate cause of the curious result arrived at by Professor BARLOW in the course of his magnetic inquiries; who observed that a hollow sphere of iron exerted the same influence on a compass needle, as if it were a solid mass. If we consider the sphere to be made up of concentric laminæ, then, by the foregoing experiment, the number of laminæ equivalent to exhaust the inductive energy of a small compass needle, will, especially in iron, (11) (Exp. *f* note,) be very few: consequently, all the interior may be removed. This is likewise consistent with a subsequent observation of the same distinguished philosopher; a certain depth of metal being found necessary. If the experiment were accurately tried, it is probable that the depth of metal requisite, would vary with the force of the compass bar; although for small needles the differences are so inconsiderable as not to be appreciable. For very powerful magnets, however, some further quantity of metal would be required; but, perhaps, in no instance could we employ a magnet of sufficient power to influence the whole mass of a solid iron sphere of large dimensions.

TABLE VI.

No. of the ring	1st	2nd	3rd	4th	5th	6th	7th	8th
Vibrations . . . .	44	76	94	124	148	166	186	210
Ratio of force.	8.54	4.52	3.45	2.38	1.83	1.53	1.25	1.0

In comparing the above numbers with those in the preceding Table, the energy of any number of rings, taken together, appears to be very nearly the sum of the same rings, taken separately, and is a curious deduction by the formula above given (16). Thus the energy of three rings combined is by the preceding Table 16.5, which is about the aggregate amount of the first, second, and third, as deduced above, and so on. It is true that some of the other numbers are not in such complete accordance as in this instance, but the approximation is nevertheless very remarkable. The intervening rings do not therefore intercept any very sensible portion of the inductive influence of the bar; a result quite consistent with what is observed in the case of rotating discs, when covered with non-ferruginous screens; and with this further condition, that whilst the inductive energy thus penetrates the intervening metal, it disturbs at the same time its magnetic distribution.

23. The foregoing deductions were verified by combining a few rings not immediately successive, so as to leave an interval between them. The results are as follow.

TABLE VII.

Rings combined .	1st + 4th	4th + 8th	1st + 4th + 8th
Vibrations . . . . .	-37	100	+33
Force . . . . .	11.3	3.2	-11.7

In these, as in the foregoing instances, it may be perceived, on comparing the actual observation, as given in this Table, with the values of the respective rings in the preceding one, that the numerical approximations are very close. The energy of any ring therefore may be estimated by subtracting from the aggregate effect, the sum of the others with which it is combined.

24. It would not be difficult, from the above investigation, to arrive at some

general conclusions as to the precise ratio in which the energy increases with the separate quantities of matter, and decreases with the distance; since both are involved in the experimental results. In the following Table is given the observed effect of each separate ring, as compared with the corresponding effect deduced by calculation from the first experiment, on the supposition that the energy is directly as the quantity of matter, and inversely as the squares of the respective distances; and it will be seen that the differences are not greater than may, from the somewhat complicated nature of the experiment, be expected.

TABLE VIII.

Rings . . . . .	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.
Energy by calculation . . . }		4.5	3.05	2.19	1.65	1.28	1.04	0.84
Observed energy	8.54	4.52	3.45	2.38	1.83	1.25	1.25	1.0

25. There appears reason therefore to conclude, as a general principle, that the transient magnetic energy of any substance, not supposed to contain iron, varies in a direct ratio of the quantity of matter within the sphere of the action, and in an inverse ratio of the squares of the distances from the magnet; the matter being supposed to be condensed into a stratum not having sensible thickness, and taken at some mean point of distance within the surface, where the sum of the forces may be imagined to produce the same effect as if exerted from every part of the mass; and the respective distances estimated between this mean distance and the opposed surface of the magnet\*.

26. It is a consequence almost necessarily resulting from the foregoing investigation, that, supposing all other circumstances alike, the energy of the same substance is directly as its density, although such did not actually appear in the foregoing experiments with various species of wood (25); but this may be readily supposed to arise from the circumstance, that the energy of wood is

\* The reason why such should be the case for the magnet has been already given (12): it is equally applicable when the energy of the extremities only is supposed to be exerted: and it may be further observed, that although on either of the sides of a magnetic bar, the point of greatest attraction of that particular side seems to fall (a little) within the extremity, yet the maximum of force of every common bar will be found invariably on the surface, terminating the extreme ends.



altogether too feeble to admit of such differences becoming appreciable by the means employed. In metallic bodies, however, the fact appears to be very decided; thus, in three specimens of copper, whose dimensions were very nearly the same, but whose specific gravities varied, the resulting energies were observed to be the greatest in those which had the greatest specific gravity; as for example, when the specific gravities were to each other as 8.30 to 8.40, the resulting number of vibrations amounted in the one instance to twelve, in the other to fifteen. To obtain more than rough approximations to the precise law by this method, would be extremely difficult, since the metals, as it is evident, should be procured in a state of great purity, and the dimensions, previously to taking the specific gravities, adjusted with an accuracy which only the most refined workmanship can effect; there is however little doubt, if the experiment could be accurately tried, that the energy of the same metallic substance would, as a general result, be in the direct ratio of its density.

27. It is of importance therefore, in estimating the comparative magnetic influence of metals, to take into account their density; without which the inquiry might prove unsatisfactory. The energies of various metallic bodies, and some few alloys, were estimated by determining the number of vibrations of the bar between  $45^\circ$  and  $10^\circ$  in a ring of each; the metal being within 0.1 of an inch of its poles. The more common metals were cast in a mould, and all the rings adjusted to the same dimensions.

28. I endeavoured to estimate the energy of mercury at  $-50^\circ$  of FAHRENHEIT, by freezing it into a solid ring, of the same dimensions as the preceding, in a mould of wood, accurately adjusted for the purpose; but could only obtain satisfactorily, as a general result, the place it appeared to hold in the scale of magnetic energy. The ring was fully and completely solidified, and the mould so constructed as to admit of its interior part being removed, so that the needle could oscillate, whilst the metal remained externally enveloped in the freezing mixture. The thermometer, previously to removing the interior of the mould and adjacent salts, stood at  $-56^\circ$ . I had not an opportunity of repeating this interesting experiment, which is sufficiently practicable, and seems to promise the development of some new phenomena in magnetism. The energy of mercury in its fluid state, in a vacuum, was examined by inclosing it be-



tween two glass circular checks, so as to obtain a ring of nearly the same dimensions as the others, subsequently separating the influence due to the glass alone.

29. The place which the following metals appear to occupy in the scale of magnetic energy, and their comparative influence, as resulting from this investigation, is given in the succeeding Tables.

TABLE IX.

Metals.	Rolled Silver.	Rolled Copper.	Cast Copper.	Rolled Gold.	Cast Zinc.	Cast Tin.	Cast Lead.	Solid* Mercury.	Cast Antimony.	Fluid Mercury.	Cast Bismuth.
Comparative magnetic energy . }	39	29	20	16	10	6.9	3.7	2.0	1.3	1.0	0.45

TABLE X.

Alloys.	Cast Copper and Zinc in equal parts.	Cast Copper and Bismuth in equal parts.	Cast Zinc and Bismuth in equal parts.
Comparative energy . . }	12	2.3	1.4

30. Although considerable pains have been taken to make the foregoing Table as perfect as possible, yet it cannot be considered as anything more than a useful approximation; there are many conditions peculiar to this inquiry to be yet investigated, which seem for the present to preclude the possibility of obtaining results quite conclusive. The metals employed were in as great a state of purity as they could be obtained in the ordinary way of commerce; some of them, more especially the copper, gold, and silver, may be considered as very nearly without alloy.

31. If the preceding investigations are of any importance, they seem to be in great measure conclusive, as to the cause of the influence of a rapidly

\* The comparative influence of solid mercury must be taken as a rough approximation; the bar in this ring in air, as nearly as could be ascertained, performed about 150 vibrations between 45° and 10°; whilst, in an analogous ring of rolled copper it performed about fourteen vibrations; in free space in air, it performed 232.

rotating metallic disc on a freely suspended magnet; whilst at the same time they are in accordance with the opinion of M. ARAGO, that almost every known substance can exert an influence on the compass-needle. Every species of matter therefore may be considered to be more or less susceptible of a state of transient magnetic energy, arising from induction.

32. The hypothesis advanced by Mr. HERSCHEL and Mr. BABBAGE in explanation of some of these phenomena is extremely simple, and to a great extent very satisfactory; inasmuch as it agrees with all the observed operations of magnetic induction, and, as stated by them, supersedes the necessity of advancing any new hypothesis in magnetism; it is nevertheless considered by M. ARAGO as insufficient\*. This celebrated philosopher appears to deny, that the limit of the motion produced by any force, which can be supposed to reside in the induced poles, even if their existence be admitted, can exceed a minute of a degree: whereas, in order to explain the rotation, it should exceed  $90^\circ$ . It may be observed however, that a ring of metal, copper for example, immediately surrounding the poles of the needle, can, as first stated by M. ARAGO, diminish the amplitude of its oscillations, and, as seen in the foregoing experiments, so fetter its motion, as to reduce the vibrations in a given space from 420 to 14. We must therefore necessarily conclude the force induced in each consecutive point of the ring to be very considerable. With non-metallic bodies, the force is certainly very much less; but these do not fetter the motion of the needle to anything like so great an extent, nor will these substances rotate, as far as I can find, by the influence of a magnet revolving in an exhausted receiver without sensible vibration, notwithstanding the rapidity of the rotation exceeds 700 revolutions in a minute.

33. After considering with much attention the hypothesis just alluded to, I am led to offer a few additional observations, with a view of extending the principle it involves, and which may possibly be useful in further elucidation of the perceived effects; whilst, at the same time, they will not be found in any way inconsistent with the known laws of magnetic action.

The facility with which a magnetic development is induced in bodies, may be designated by the term "susceptibility"; the time during which this effect of induction remains in them "retentive power". These terms have been

\* Edin. Philos. Journal, vol. v. p. 326.

already employed by Mr. BABBAGE and Mr. HERSCHEL, and they are sufficiently explanatory. In the case of magnetic energy induced in a body by any of the ordinary methods, it may be observed as a general fact, that the energy is acquired in somewhat less time than that in which it is again lost. This is particularly the case in soft iron rendered magnetic, by an electro-magnetic spiral; a simple contact between a magnet and a mass of soft iron will frequently convey to it an attractive force, which it retains for a comparatively long space of time. In regard to the susceptibility of different substances, it is found to vary considerably; and depends on some peculiar property not yet explained; it seems to be in some inverse ratio of their retentive power. Thus it is not without difficulty that hardened steel is made permanently magnetic, whilst its retentive power is considerable: soft iron, on the contrary, is observed to be comparatively feeble in its retentive power, whilst its susceptibility of magnetic change is great. It may be hence inferred, that in non-ferruginous masses, the mere susceptibility of magnetic change, is in fact also considerable, but then their retentive power is so feeble, that the subsequent attraction does not ensue to any great extent. This probably arises from some peculiar state of the particles of these substances, which allows what may be termed the new magnetic distribution, to tend more rapidly to the previous state of neutrality, immediately the tension passes a certain point. In every observed instance, however, more time seems necessary to restore perfectly, the original state of the body, than was required to disturb it, the former being the result of a progressive operation, whilst the latter is effected by a sudden and concentrated force.

34. The attraction, as usually observed, between a magnet and a mass of iron, is invariably preceded by this new magnetic distribution in the iron; and unless such new distribution can occur, it seems, as in the analogous operation of electrical action, that no attractive effect can ensue; indeed this is made evident by the repulsive efforts of two similar magnetic poles; the repulsion may be conceived to be really the immediate consequence of an inductive effort, since an attempt is made to reverse the magnetic distribution in the opposed bars, which action the already existing polarities resist: when, however, as in the case of opposing either pole of a very powerful



magnet to the similar pole of a very weak one, this new distribution can be effected, an attractive force immediately follows.

35. There are some circumstances connected with this curious result of magnetic action, which seem to apply immediately to the question under consideration, but which have not been generally observed. If two similar magnetic poles of very unequal force be opposed to each other, the greatest repulsion, taking into account the difference in distance, will be a little within the limit of their action: that is to say, the increments in the repulsive energy are comparatively less, as the magnets approach each other: evidently resulting from the change which begins to take place in the magnetism of the bars. Now if one of the bars be extremely powerful in regard to the other, the new distribution in the weaker bar is effected even before the point of contact. The precise point at which the existing polarity of the weaker bar becomes changed varies with the force of the stronger magnet. This point may be found by experiment in the following way. Let a small cylindrical magnet be suspended by a silk line from a delicate wheel, whose axis rests on friction rollers; and let it be counterpoised by a small weight at the extremity of a short cylindrical piece of wood partly immersed in a jar of water. If one pole of a powerful bar be now carefully approximated towards the like pole of the suspended magnet, by fixing the former in a brass frame carrying a micrometer-screw, the latter will be observed to recede from the bar, until the opposed poles are within a certain distance of each other; when the repulsion will cease, and a weak attractive effect ensue. The cylinder of wood as it becomes gradually immersed\*, continually furnishes an equivalent to the repulsion, in the quantity of water displaced.

We do not generally perceive the attractive effect resulting from this inductive action in non-ferruginous masses; for, as already observed, their feeble retentive power admits of the magnetic neutrality being more rapidly restored, when the tension passes a certain point. So that in fact, the opposite magnetic state never becomes sufficiently intense to evince an attractive force, cognizable by the ordinary means.

\* A more detailed account of this experiment may be found in the Transactions of the Royal Society of Edinburgh.

36. When, therefore, a disc of any substance is put into a state of rotation under a suspended magnetic bar, opposite poles are induced in that part of the disc immediately under the bar; these induced poles may be supposed to pass on, and being retained for a short portion of time, will, if the motion be more rapid than the time during which the impression remains, be transferred toward the opposite poles of the magnet, and exert upon them a repulsive action up to that point of distance (35) at which the poles of the magnet again reverse the transient poles impressed on the disc, and substitute opposite poles, to be again reversed as before.

37. Thus if  $NsSn$  (fig. 12) be a metallic disc revolving in the direction  $NsSn$  under a magnetic bar  $NS$  free to move upon a central point  $C$ , and of which  $N$  is the north pole, and  $S$  the south, the effect of this rotation will be, to impress upon the semicircle  $NsS$  a south polarity, and upon the semicircle  $SnN$  a north polarity, in consequence of the points  $sss$  and  $nnn$  having passed under the poles  $N$  and  $S$ . Now if the time required to restore the original magnetic distribution of the plate, be less than that necessary to disturb it, these impressed polarities remain for a small portion of time, and hence there will always be an attractive force in advance of the poles of the bar, and a repulsive force in arrear of them; consequently the bar becomes driven, as well as dragged in the direction of the revolving disc by the resolved portion of the oblique actions acting for the most part near the extremities. And there is little doubt, that any substance in the least degree susceptible of a transient magnetic state, might cause a magnet to rotate; provided that the rapidity of the motion be greater than the time necessary for the restoration of the original magnetic distribution of the body acted on; supposing such rapidity of rotation possible.

38. A rotating disc, therefore, circumstanced as above (37), may be considered as a circular magnet such as that already mentioned (5), one of the semicircles having a north polarity, and the opposite semicircle a south polarity; and which polarities eventually neutralise each other about one of the diameters; the only difference being, that the magnetism of the revolving disc is transient, and constantly changing its position; so that the neutral points are always near the poles of the suspended bar. The bar therefore by a well-

known law of magnetic attraction, will be constantly endeavouring to place itself at right angles to the magnetic equator of the disc, whilst the position of the latter varies in its turn with the position of the bar : it is in fact owing to this circumstance that the bar at length revolves with the disc, as may be in great measure seen by substituting for the disc a similar disc of steel made permanently magnetic ; in which case the suspended bar will not revolve, it will be merely put into a state of disturbed vibration.